Building America Research Benchmark Definition

Version 3.1, November 11, 2003

This report summarizes the specifications for the Building America Research Benchmark Version 3.1, with guidelines for reporting analytical results using the Benchmark in studies that include consideration of current regional and builder standard practice. Version 3.1 of the Benchmark is generally consistent with the 1999 HERS Reference Home as defined by NASEO/RESNET, with additions that allow evaluation of all home energy uses.[1] Additional documentation to support the use of the Benchmark, including spreadsheets with detailed hourly energy usage and load profiles, can be found on the Building America web site.[2] As Building America teams develop innovative new technologies and systems approaches that move the program toward its research goals, the Benchmark will occasionally be evaluated and updated to ensure that energy savings from these features are accurately credited.

The Building America Research Benchmark was developed to track and manage progress towards long term, average whole building energy reduction research goals using a fixed reference point. User profiles have been developed based on review of the available literature with the intent of representing average occupant behavior. Additional analysis and end use monitoring are required to evaluate energy savings for specific occupants whose individual behavior may vary from the average profiles defined in the Benchmark (Norton, 2003). In general, the relative savings for an individual user are expected to be approximately the same as for an average user.

The primary use for the Benchmark is to establish performance targets for individual research projects relative to multi-year whole house energy efficiency research goals for DOE's national residential research program. To provide a context for the potential impacts of research projects on local and regional markets at any given point in time, energy savings are also compared to current regional standard practice and builder standard practice (Hendron, 2001). The use of a fixed research benchmark, combined with points of reference for current regional and builder standard practice, provides a mechanism to both track progress towards multi-year research goals and ensure that individual research projects are relevant to current builder needs.

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[1] The current HERS rating process is based on hot water and space conditioning loads only. Amendments to include additional end-uses such as lighting and appliances are currently under consideration by RESNET.

[2] http://www.eere.energy.gov/buildings/building_america/benchmark.shtml

Building Envelope

All building envelope components (including walls, windows, foundation, roof, and floors) for the Benchmark shall be consistent with the HERS Reference Home as defined by NASEO/RESNET in "National Home Energy Rating Technical Guidelines" dated September 19, 1999 (NASEO, 1999). These requirements are summarized below, along with a few minor clarifications and additional requirements. References to U-values in the 1993 Model Energy Code (MEC) have been updated to 2003 International Energy Conservation Code (IECC), because the corresponding graphs are identical and the IECC is more readily available (ICC 2003).

- The same shape and size as the Prototype.
- The same area of surfaces bounding conditioned space as the Prototype, with the exception of the attic, which shall be insulated at the attic floor and have a ventilation area of 1 ft^2 per 300 ft^2 ceiling area regardless of the Prototype attic design.
- The same foundation type as the Prototype.
- The same basement wall construction type as the Prototype (i.e. masonry, wood-frame, etc.)
- No sunrooms
- No skylights.
- Window area (A_F) determined:
    - For detached homes, by Equation 1
    - For attached homes, by Equation 2.

Equation 1: $$A_F = 0.18 \times A_{FL} \times F_A$$

Equation 2: $$A_F = 0.18 \times A_{FL} \times F_A \times F$$

Where:
A_F = Total window area
A_{FL} = Total floor area, including basement
F_A = (Exposed thermal boundary wall area)/(total thermal boundary wall area).
F = (Total thermal boundary wall area)/(total thermal boundary wall area + common wall area), or 0.56, whichever is greater.

And where:
Total thermal boundary wall is any wall that separates directly or indirectly conditioned space from unconditioned space or ambient conditions, including all basement walls but not including unvented crawlspace walls.
Exposed thermal boundary wall is any thermal boundary wall not in contact with soil.
Common wall area is the total area of walls adjacent to another conditioned living unit, including basement and directly or indirectly conditioned crawl space walls.

- Window area shall be assigned according to the following requirements:
    - Distributed equally in each of the four cardinal directions (north, south, east and west). For the purpose of orientation neutrality in attached homes, this may require windows located in common walls.

- Vertical distribution on each façade shall be in proportion to the fraction of exposed thermal boundary wall area on the façade associated with each floor, including the basement. If the modeling tool does not allow windows in basement walls, then window area shall be distributed in proportion to the external wall area of the façade for above-grade floors.

- Thermal conductance of all enclosure elements equal to the requirements, expressed as U and U_o values, of Paragraph 502.2 of the 2003 International Energy Conservation Code (ICC 2003), as summarized below. Unless otherwise specified, these U-values are for entire assemblies, including sheathing, framing, finishes, etc.
    - Total wall assembly U_o from Figure 1 (excerpted from ICC 2003).
    - U-value (U_w) for opaque walls from Table 1a or 1b.

Table 1a. Opaque wall U-values (U_w) for detached homes

Annual heating degree days base 65 (HDD65) from nearest location listed in Chapter 9 of ASHRAE Standard 90.2 or NREL's Solar Radiation Data Manual[3]	U_w air to air Includes framing
> 13000	0.038
9000-12999	0.046
6500-8999	0.052
4500-6499	0.058
3500-4499	0.064
2600-3499	0.076
<2600	0.085

Table 1b. Opaque wall U-values (U_w) for attached homes

Heating degree days base 65 (HDD65) From nearest location listed in Chapter 9 of ASHRAE Standard 90.2, or NREL's Solar Radiation Data Manual	U_w air to air Includes framing
>9000	0.064
7100-8999	0.076
3000-7099	0.085
2800-2999	0.100
2600-2799	0.120
<2600	0.140

[3] See "Solar Radiation Data Manual for Buildings" (or the "Blue Book") published by the National Renewable Energy Laboratory (http://rredc.nrel.gov/solar/old_data/nsrdb/bluebook/).

- The U-value for windows shall be calculated using Equation 3 or shall be equal to 1.3, whichever is less.

Equation 3: $U_F = [(U_o \times A_o)-(U_w \times A_w)-8]/A_F$

Where:

U_F = Required average U-value of the windows, including framing and sash.
U_o = Average U-value requirement for walls from Figure 1.
A_o = Gross exposed wall area, not including basement or crawlspace walls, of the Prototype.
U_w = U-value from Table 1a or 1b.
A_w = Net opaque wall area, calculated as: A_o - A_F - 40.
A_F = Area of windows

Note: For walls of attached homes, the U-value calculation in Equation 3 is completed using the total window area calculated as A_F and the actual area of walls that experience heat loss or gain. Areas of common walls that separate homes are not included in A_o.

  - U-value of an insulated floor above a vented crawlspace or other unconditioned space shall be as specified Figure 2 (excerpted from ICC 2003).
  - U-value of insulated walls in an unvented crawlspace shall be as specified Figure 3 (excerpted from ICC 2003).
  - U-value of insulated basement walls shall be as specified in Figure 4 (excerpted from ICC 2003), and the insulation shall be located on the interior surface of the walls.
  - U-value and depth of slab edge insulation for slab-on-grade construction shall be as specified in Figure 5 (excerpted from ICC 2003).
  - U-value of insulated roof/ceiling shall be as specified in Figure 6 (excerpted from ICC 2003). If the Prototype includes an attic, the roof/ceiling insulation for the Benchmark shall be located at the attic floor.

- Solar Heat Gain Coefficient (SHGC) equal to 0.581 for window assemblies, including the effects of framing and sash.
- No external shading at any time from roof projections, awnings, adjacent buildings, trees, etc. Basic architectural features such as attached garages and enclosed porches shall be included in the Benchmark model, but it shall not include window shading effects from these features.
- No self-shading shall be modeled for either the Prototype or Benchmark.
- Interior shading multiplier = 0.7 during the cooling season, and 0.85 during the heating season and during swing seasons when both cooling and heating occur. Seasons are defined in the section entitled “Operating Conditions”.
- Total area of opaque exterior doors equal to 40 ft^2, facing north, and with door U-value equal to 0.20.

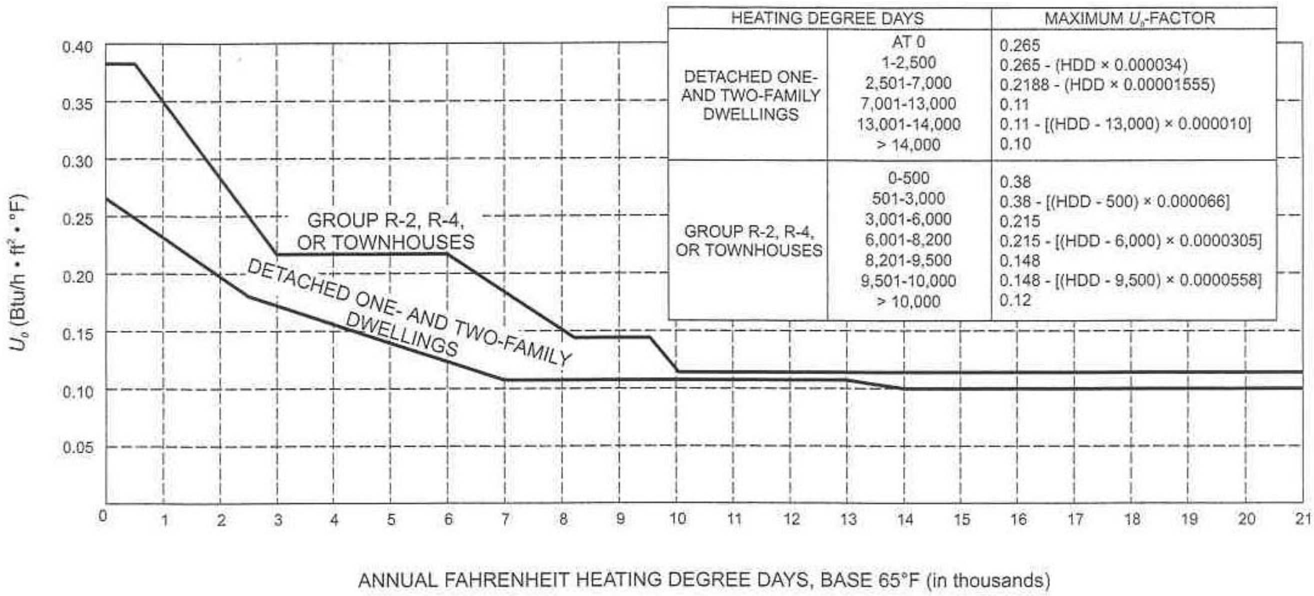

Figure 1. Wall assembly U-value (U_0). (Excerpted from ICC 2003)

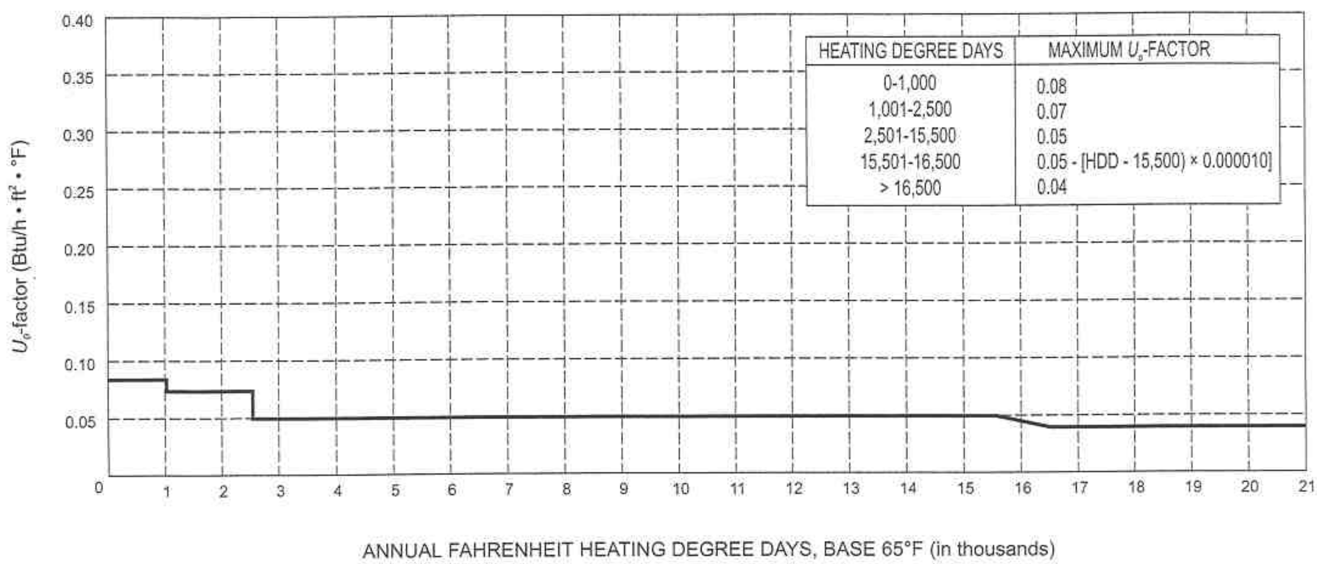

Figure 2. U-value of floor over unconditioned space. (Excerpted from ICC 2003)

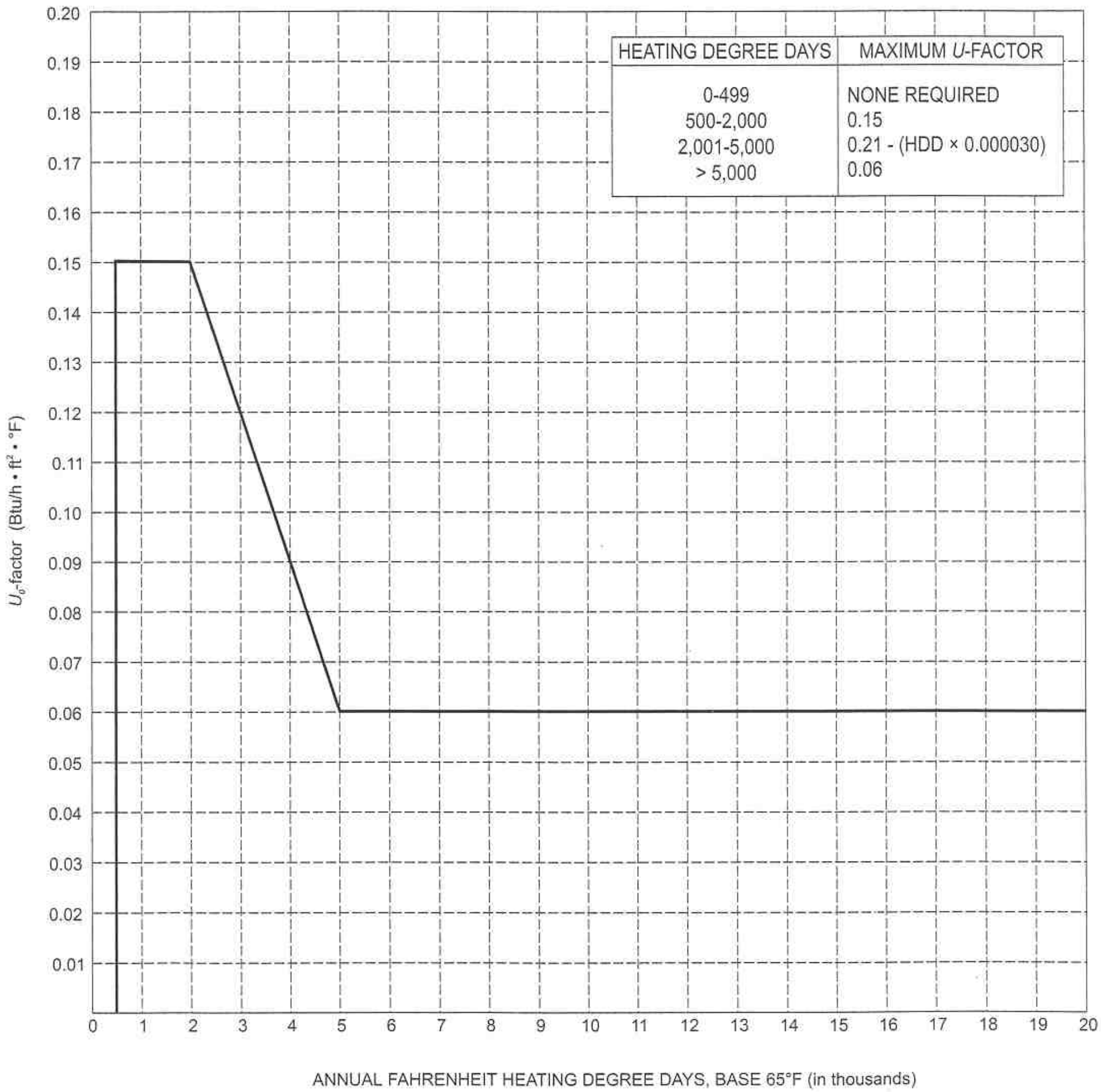

Figure 3. Unvented crawlspace wall U-value. (Excerpted from ICC 2003)

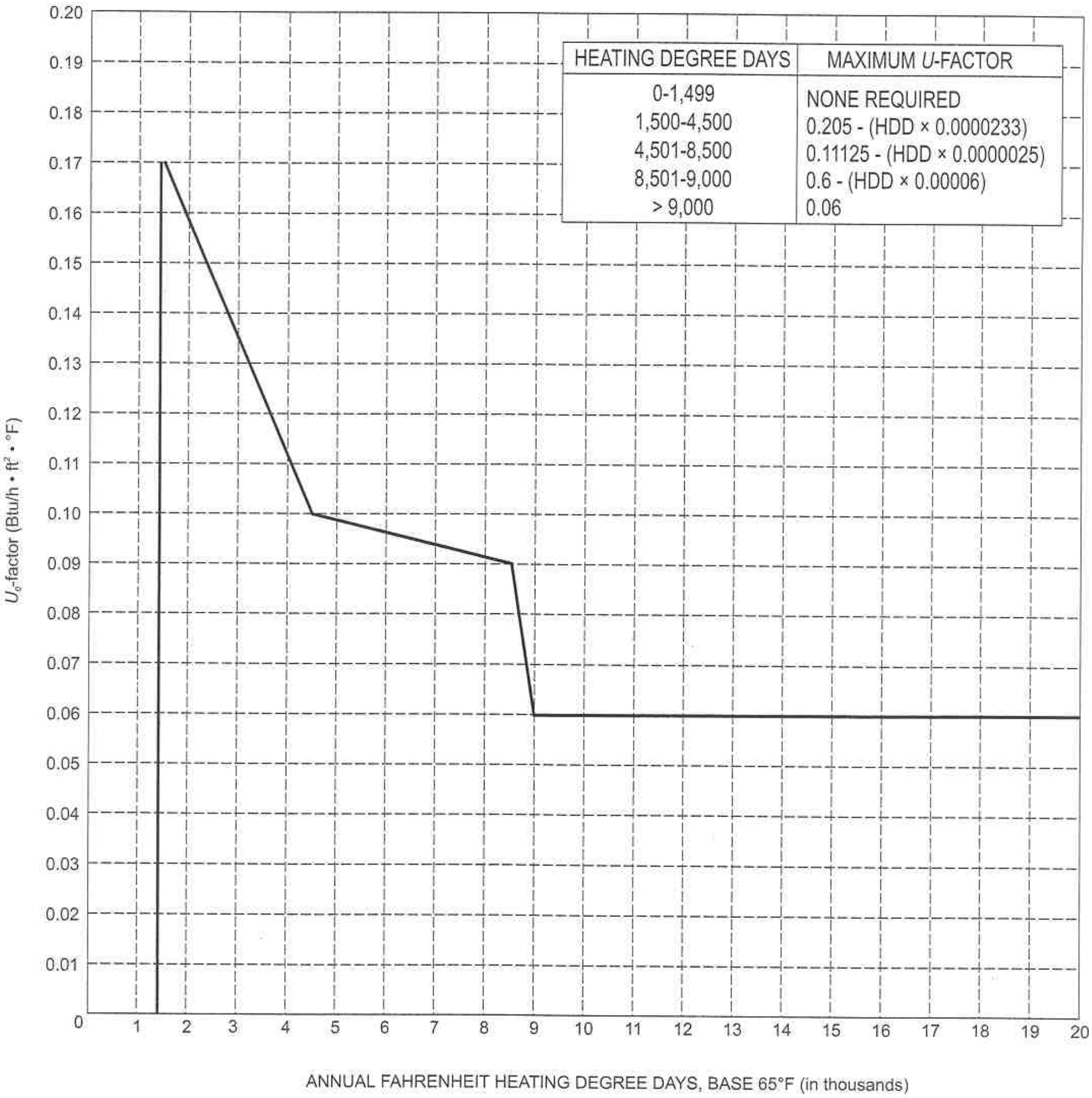

Figure 4. Basement wall U-value. (Excerpted from ICC 2003)

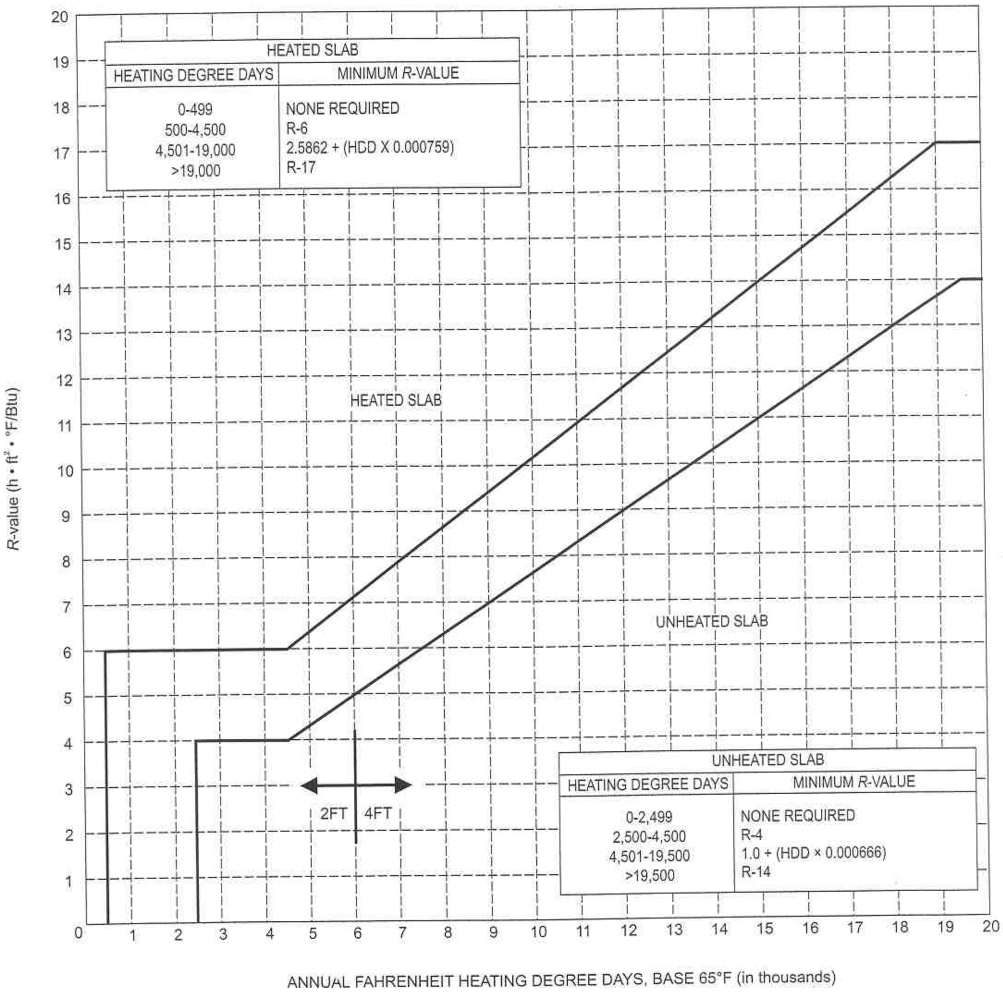

Figure 5. Slab insulation R-value and depth. (Excerpted from ICC 2003)

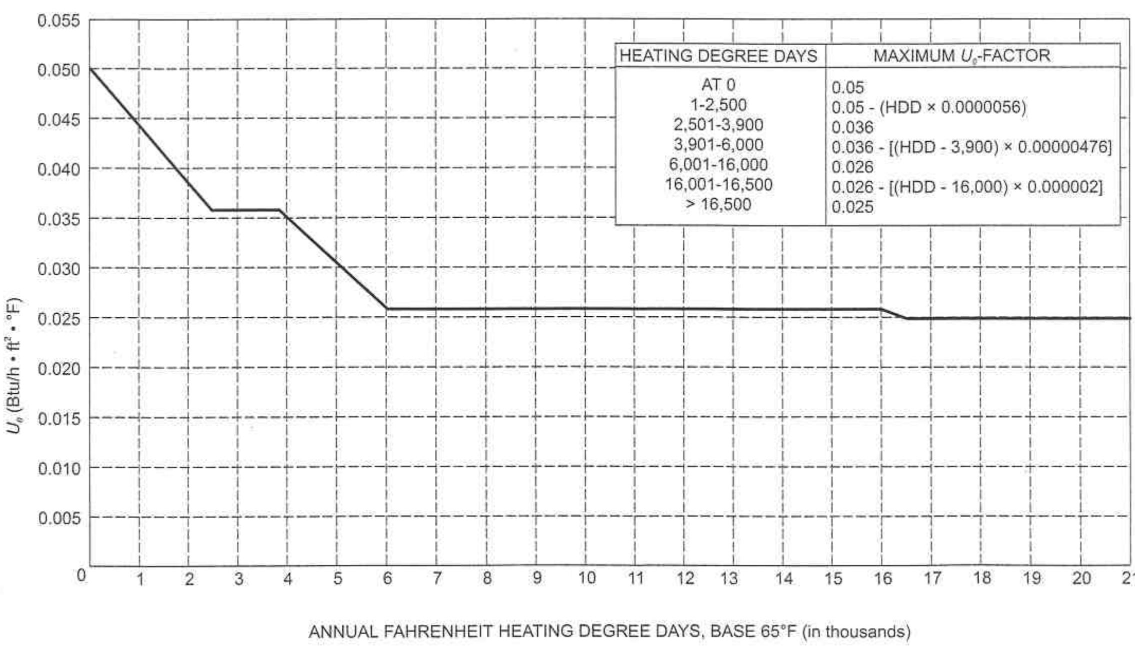

Figure 6. Roof/ceiling assembly U-value. (Excerpted from ICC 2003)

- Solar absorptivity equal to 0.50 for opaque areas of exterior walls, and 0.75 for opaque areas of roofs.
- Total emittance of exterior walls and roofs = 0.90.
- The above-grade exterior walls shall be light-frame 2x4 or 2x6 wood construction with sufficient insulation to achieve the correct overall U-value. The default framing factors provided in Table 2 may be used for the Prototype house if the actual framing factor is unknown. The values highlighted in gray are representative of typical construction practices, and shall be used as inputs for the Benchmark model.
- Interior walls shall be light-frame (2x4) wood construction.
- Masonry floor slabs with 80% of floor area covered by R-2 carpet and pad, and 20% of floor area directly exposed to room air

Table 2. Benchmark and Prototype Default Framing Fractions.

Enclosure Element	Frame Spacing (inches o.c.)	Default Frame Fraction (% area)
Walls (standard framing):		
@16" o.c.	16	23%
@24" o.c.	24	20%
Walls (advanced framing):		
@16" o.c.	16	19%
@24" o.c.	24	16%
Structural Insulated Panels	48	10%
Floors (standard framing):		
@16" o.c.	16	13%
@24" o.c.	24	10%
Floors (advanced framing):		
@16" o.c.	16	11%
@24" o.c.	24	8%
Ceilings (standard trusses):		
@16" o.c.	16	14%
@24" o.c.	24	11%
Ceilings (advanced trusses – "raised heel"):		
@16" o.c.	16	10%
@24" o.c.	24	7%
Ceilings (conventional framing):		
@16" o.c.	16	13%
@24" o.c.	24	9%

Space Conditioning/Air Distribution Equipment

Space conditioning equipment type and efficiency for the BA Benchmark shall meet the following requirements:

- The minimum NAECA efficiency in effect on January 1, 1992 for the same type of HVAC equipment, including the air handler, found in the Rated Home except that the efficiencies given in Table 3 will be assumed when:
  a) A type of device not covered by NAECA is used in the Prototype.
  b) The Prototype is heated by electricity using a device other than an air source heat pump.
  c) The Prototype does not have a heating system and there is at least one month where heating is required (see section entitled "Operating Conditions")
  d) The Prototype does not have a cooling system.
- Heating and cooling equipment shall be sized using the procedures published by the Air Conditioning Contractors of America (ACCA). (**www.accaconference.com/Merchant2/merchant.mv?Screen=CTGY&Store_Code=ACCOA&Category_Code=M**)
- The Benchmark shall not have a whole-house fan.
- The Benchmark air handler shall have power consumption equal to 0.00055 kW/CFM.

The air distribution system in the Benchmark shall have the properties listed in Table 4, with duct location determined based on air handler location in the Prototype (CEC, 1998). If the simulation tool does not permit the input of duct specifications to this level of detail, then two values (one for heating, one for cooling) of seasonal distribution system efficiency (DSE) shall be estimated and applied to the heating and cooling system efficiencies to represent typical losses from ducts. The values of DSE shall be determined using Table 4 and the procedures in Draft ASHRAE Standard 152P. A spreadsheet developed by LBNL is posted on the Building America web site[4] to assist with this calculation.

Table 3. Benchmark space conditioning equipment efficiencies

Prototype Equipment	Function	Benchmark Space Conditioning Device
Electric or No System	Heating	6.8 HSPF Air Source Heat Pump
Non Electric Boiler	Heating	80% AFUE Gas Boiler
Non Electric Warm Air Furnace or Other Non-Electric Heating	Heating	78% AFUE Gas Furnace
Any Type or No System	Cooling	10 SEER Electric Air Conditioner

[4] http://www.eere.energy.gov/buildings/building_america/benchmark.shtml

Table 4. Duct Locations and Specifications for Benchmark

	Prototype Air Handler Location†	Benchmark Duct Specification	
		One-Story	*Two-Story or Higher*
Supply Duct Surface Area (ft^2)	All	0.27 x FFA‡	0.20 x FFA
Return Duct Surface Area (ft^2)	All	0.05 x $N_{returns}$ x FFA (Maximum of 0.25 x FFA)	0.04 x $N_{returns}$ x FFA (Maximum of 0.19 x FFA)
Supply Duct Insulation (Conditioned Space)	All	R-3.3	
Return Duct Insulation (Conditioned Space)	All	None	
Supply/Return Duct Insulation (Unconditioned Space)	All	R-5.0	
Duct Material	All	Sheet Metal	
Duct Leakage (Inside + Outside)	All	10% of Air Handler Flow (6.5% Supply, 3.5% Return) (Percentage lost to outside equal to percentage of duct area in unconditioned space, as specified below)	
Supply Duct Location	Attic	100% Attic	65% Attic, 35% Conditioned Space
	Crawlspace	95% Crawlspace, 5% Unconditioned Space	60% Crawlspace, 35% Conditioned Space, 5% Unconditioned Space
	Basement	95% Basement, 5% Unconditioned Space	60% Basement, 35% Conditioned Space, 5% Unconditioned Space
	Other Location or Ductless System (≥ 5000 HDD)	95% Basement (Or attic if prototype has no basement), 5% Unconditioned Space	60% Basement (Or attic if prototype has no basement), 35% Conditioned Space, 5% Unconditioned Space
	Other Location or Ductless System (< 5000 HDD)	100% Attic	65% Attic, 35% Conditioned Space
Return Duct and Air Handler Location	Attic	100% Attic	100% Attic
	Crawlspace	95% Crawlspace, 5% Unconditioned Space	95% Crawlspace, 5% Unconditioned Space
	Basement	95% Basement, 5% Unconditioned Space	95% Basement, 5% Unconditioned Space
	Other Location or Ductless System (≥ 5000 HDD)	95% Basement (Or attic if prototype has no basement), 5% Unconditioned Space	95% Basement (Or attic if prototype has no basement), 5% Unconditioned Space
	Other Location or Ductless System (< 5000 HDD)	100% Attic	100% Attic

† If the prototype has more than one air handler, the properties of the benchmark air distribution system shall be apportioned based on the capacity of each air handler.
‡ Finished Floor Area.

Domestic Hot Water

For the domestic hot water system in the Building America benchmark, the assumptions in Table 5 shall be made. Storage and burner capacity is determined using the guidelines recommended by ASHRAE in the HVAC Applications Handbook (ASHRAE, 1999), which are based on the minimum capacity permitted by HUD-FHA (HUD, 1982). Energy Factor is the NAECA minimum for the specified fuel type and storage capacity (DOE, 2002a). An example set of DHW specifications for a typical 3 bedroom, 2 bathroom prototype is shown in Table 6. A spreadsheet with many of these equations automated can be downloaded from the Building America website (http://www.eere.energy.gov/buildings/building_america/docs/appliance_dhw_2003_05_30.xls).

Table 5. Characteristics of Benchmark domestic hot water system.

	Water Heater Fuel Type in Prototype	
	Electric	*Gas*
Storage Capacity (V) (Gallons)	See *ASHRAE HVAC Applications 1999*	See *ASHRAE HVAC Applications 1999*
Energy Factor (EF)	0.93 – (0.00132 x V)	0.62 – (0.0019 x V)
Recovery Efficiency (RE)	0.98	0.76
Burner Capacity	See *ASHRAE HVAC Applications 1999*	See *ASHRAE HVAC Applications 1999*
Supply Temperature	120°F	
Fuel Type	Same as prototype[5]	
Tank Location	Same as prototype	

Table 6. Example characteristics of Benchmark domestic hot water system for a prototype with 3 bedrooms and 2 bathrooms.

	Water Heater Fuel Type in Prototype	
	Electric	*Gas*
Storage Capacity (V) (Gallons)	50	40
Energy Factor (EF)	0.86	0.54
Recovery Efficiency (RE)	0.98	0.76
Burner Capacity	5.5 kW	36,000 Btu/hr
Supply Temperature	120°F	
Fuel Type	Same as prototype	
Tank Location	Same as prototype	

Standby heat loss coefficient is calculated using the following equation based on the DOE energy factor test procedure (DOE, 2000):

[5] If the prototype does not have a domestic hot water system, or the hot water system uses solar energy or a fuel other than gas or electricity, the Benchmark shall use the same fuel for water heating as that used for space heating.

$$UA = \frac{\frac{1}{EF} - \frac{1}{RE}}{67.5 \bullet \left(\frac{24}{Qout} - \frac{1}{RE \bullet Pon} \right)} \frac{Btu}{hr \bullet {}^\circ F}$$

where: UA = Standby heat loss coefficient
EF = Energy factor
RE = Recovery efficiency
P_{on} = Burner capacity (Btu/hr)
Q_{out} = 41,094 Btu/day

Four major end-uses are identified for domestic hot water: showers, sinks, dishwasher, and clothes washer. The average daily water consumption by end-use is shown in Table 7. The specified volume is the combined hot and cold water for showers and sinks, which allows hot water use to fluctuate depending on cold water (mains) temperature. Hot water usage for the clothes washer and dishwasher are derived from the EnergyGuide labels for the least efficient of several common models sampled by NREL. For showers and sinks, the water usage is based on the average of four domestic hot water studies (Christensen, 2000; Burch, 2002; ASHRAE, 1999; and CEC, 2002).

Table 7. Domestic hot water consumption by end-use.

End-Use	End-Use Water Temperature	Water Usage
Clothes Washer	N/A	7.5 + 2.5 x N_{br} gal/day (Hot Only)
Dishwasher	N/A	2.5 + 0.833 x N_{br} gal/day (Hot Only)
Shower and Bath	105°F	14 + 4.67 x N_{br} gal/day (Hot + Cold)
Sinks	105°F	10 + 3.33 x N_{br} gal/day (Hot + Cold)

The typical ASHRAE hot water use profile is adequate for analyzing most applications, as shown in Figure 7 (ASHRAE, 1999). NREL is currently investigating profiles for individual hot water end-uses. In the meantime, the ASHRAE profile shall be used for each hot water-consuming appliance, as well as sinks and showers.

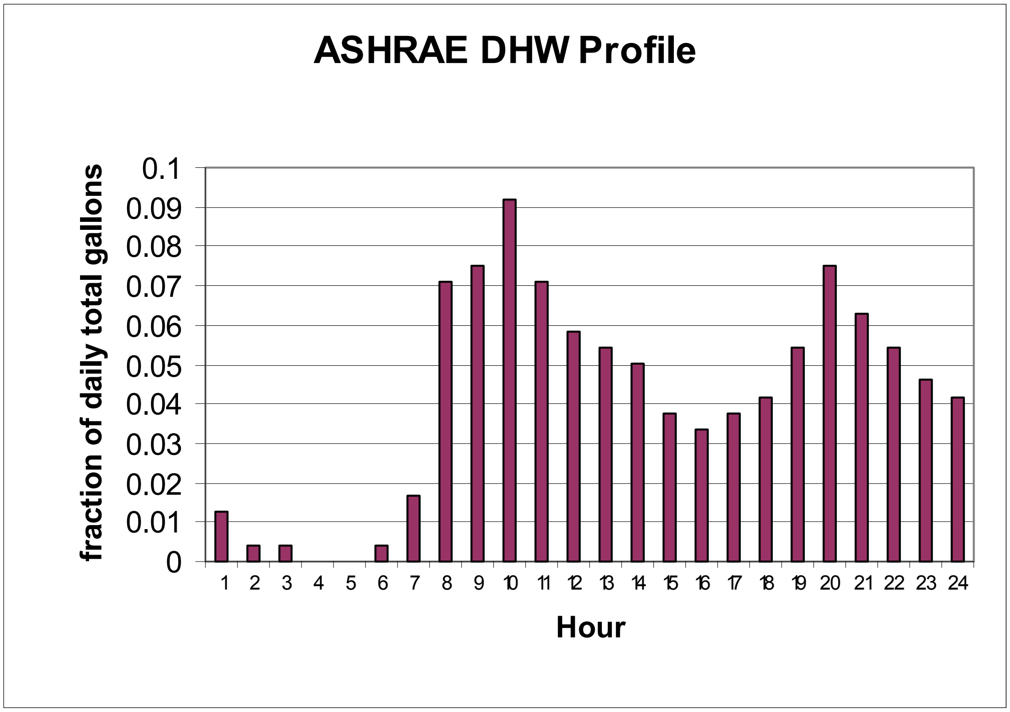

Figure 7. ASHRAE hot water use profile (ASHRAE, 1999).

Detailed event schedules may be needed for certain hot water applications. Example schedules are provided in the Excel spreadsheets posted on the Building America web site.

The mains water temperature for a typical house varies significantly depending on location and time of year. The following equation, based on TMY2 data for the location of the Prototype, shall be used to determine daily mains water temperature for both the Benchmark and Prototype:

$$T_{mains} = (T_{amb,avg} + \mathit{offset}) + \mathit{ratio} * (\Delta T_{amb,max} / 2) * \sin(0.986 * (day\# - 15 - \mathit{lag}) - 90)$$

where

T_{mains}	= mains (supply) temperature to domestic hot water tank
$T_{amb,avg}$	= annual average ambient air temperature
$\Delta T_{amb,max}$	= maximum difference between monthly average ambient temperatures (e.g., $T_{amb,avg,july} - T_{amb,avg,january}$)
0.986	= degrees/day (360/365)
day#	= Julian day of the year (1-365)
offset	= 6 °F
ratio	= $0.4 + 0.01 (T_{amb,avg} - 44)$
lag	= $35 - 1.0 (T_{amb,avg} - 44)$

This equation is based on analysis by Craig Christensen and Jay Burch of NREL using data for multiple locations compiled by Abrams and Shedd (Abrams, 1996), Danny Parker of FSEC and others. The *offset, ratio* and *lag* factors were determined by fitting the available data. The climate-specific *ratio* and *lag* factors are consistent with water pipes being buried deeper in colder climates. The *offset* factor is probably due to solar heating of ground surface.

In order for the constant terms in the *ratio* and *lag* factors to be representative of an average climate, the data fitting was done relative to a nominal $T_{amb,avg}$ = 44 ^{o}F. The *lag* is relative to ambient air temperature, and $T_{amb,minimum}$ is assumed to occur in mid-January (day# = 15). The choice of these nominal values is not critical, because while different assumptions would change the constant terms in the *ratio* and *lag* factors, the coefficients would also change so that the prediction of T_{mains} values would be unchanged.

For models that use average monthly mains temperature, the above equation shall be used with

day# = 30 * month# -15

Where: month# = month of the year (1 –12)

The installation of energy-saving appliances or other equipment may reduce hot water consumption for certain end-uses. Energy savings calculations for the Prototype shall take these effects into account, using operating conditions based on rules developed for the Department of Energy residential appliance standards (DOE, 2003b). The number of cycles per year specified in the appliance standards for clothes washers and dishwashers shall be adjusted based on number of bedrooms using the following equation:

Benchmark cycles per year = (Standard cycles per year) x (½ + N_{br}/6)

Air Infiltration and Ventilation

The natural air change rate for the BA Research Benchmark shall be based on the annual average ACH determined using the following equation:

$$ACH = L_n \times W \times F_B$$

Where ACH = (Volumetric rate at which outside air enters the home) / (building volume including all directly or indirectly conditioned basements and crawlspaces)

L_n = Normalized leakage = 0.75

W = Weather factor from W tables in ASHRAE Standard 136-1993 for the site most climatalogically representative of the Prototype location.

F_B = (Exposed thermal boundary surface area)/(total thermal boundary surface area).

And where:

Total thermal boundary surface area is the area of all surfaces that separate directly or indirectly conditioned space from unconditioned space or ambient conditions, including the walls and floors of unvented crawlspaces and directly or indirectly conditioned basements.

Exposed thermal boundary surface area is the area of all thermal boundary surfaces not in contact with soil. An exception is the area of floors over unconditioned basements, which shall not be considered exposed in the calculation of F_B.

If the simulation tool is capable of calculating hourly air infiltration, an Effective Leakage Area or other input may be specified, as long as the annual average ACH is approximately equal to the value calculated above. No additional air exchange due to mechanical ventilation shall be assumed for the Benchmark.

A mechanical ventilation system shall not be present in the BA Benchmark house unless it is specified in the prototype, in which case the following fan energy use shall be assumed for the Benchmark:

$$\text{Ventilation fan energy (kWh/yr)} = 0.03942 \times FFA + 29.565 \times (N_{br} + 1)$$

Where FFA = finished floor area (ft^2)

N_{br} = number of bedrooms

Note that finished floor area is used in this equation instead of conditioned floor area. It is believed that finished floor area more accurately represents the area used by occupants for their daily activities (see also the treatment of lighting and plug loads).

Lighting Equipment & Usage

The total annual lighting use for the BA Benchmark shall be determined using the following equations, which are derived from data in a study conducted by Navigant for DOE (Navigant 2002).

> Interior Lighting = (FFA * 0.8 + 455) kWh/yr
> Garage Lighting = 100 kWh/yr
> Exterior Lighting = 250 kWh/yr

Annual indoor lighting kWh is a function of finished house area, while garage and exterior lighting are constants. This equation correlates well with other lighting references[6], and is based on an assumption that 90% of interior lighting is from fixtures that contain incandescent lamps. The other 10% of the fixtures are assumed to have fluorescent lamps, and these are assumed to be located in the kitchen (or living area for simulation purposes).

Lighting energy use for the Prototype shall be the same as the Benchmark unless the team develops a comprehensive set of lighting specifications that addresses both builder and occupant controlled lighting. To take credit for lighting energy savings, communications materials must be presented to the homebuyer encouraging the use of energy efficient lighting in high-use locations and providing guidance for selecting and purchasing lamps.

Energy savings may be calculated based on a number of usage variations depending on the capability of the modeling tool. Variations include day types (weekday vs. weekend), occupancy types (day-use vs. non-day-use or “nuclear” vs. “yuppie”), season (summer vs. winter), and room types (living area vs. bedroom area).

The load shape for interior lighting use is shown in Figure 8, and is based on a draft LBNL report by Huang and Gu (Huang 2002), but modified slightly to be consistent with the “rolled-up” detailed profiles. This load shape shall also be used for exterior and garage lighting. Monthly variations in the load shape and lighting energy use due to changing day length can be accounted for so long as the variation is applied to all of the simulation models and the total annual energy use remains the same. (note: Title-24 has a table of monthly lighting factors that account for extended use during the winter). Modifications to the lighting profile due to occupancy sensors or other controls can also be considered for the Prototype model. Negative or positive effects on space conditioning load shall be considered, assuming 100% of interior lighting energy contributes to the internal load.

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[6] These references include the draft “HERS Proposed Amendment 2002-047 – Incorporation of Lighting and Appliances”, the draft LBNL report “Prototypical Residential Buildings To Represent the U.S. Housing Stock”, and default values from the Visual DOE software and LBNL’s Home Energy Saver software.

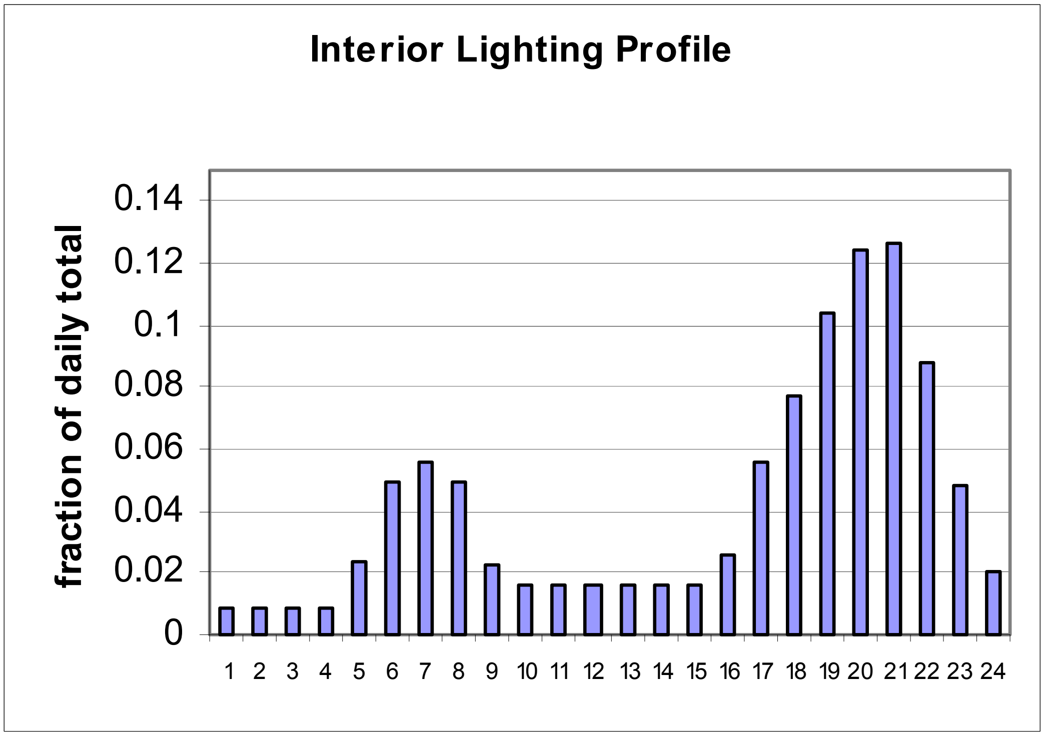

Figure 8. Interior lighting profile (built-up from detailed profiles)

Individual profiles can be "rolled up" to various levels of detail, appropriate to the simulation model. An example of one detailed set of profiles developed by NREL is shown in Figure 9. Other profiles are included in the Excel spreadsheets available from NREL through the Building America web site.

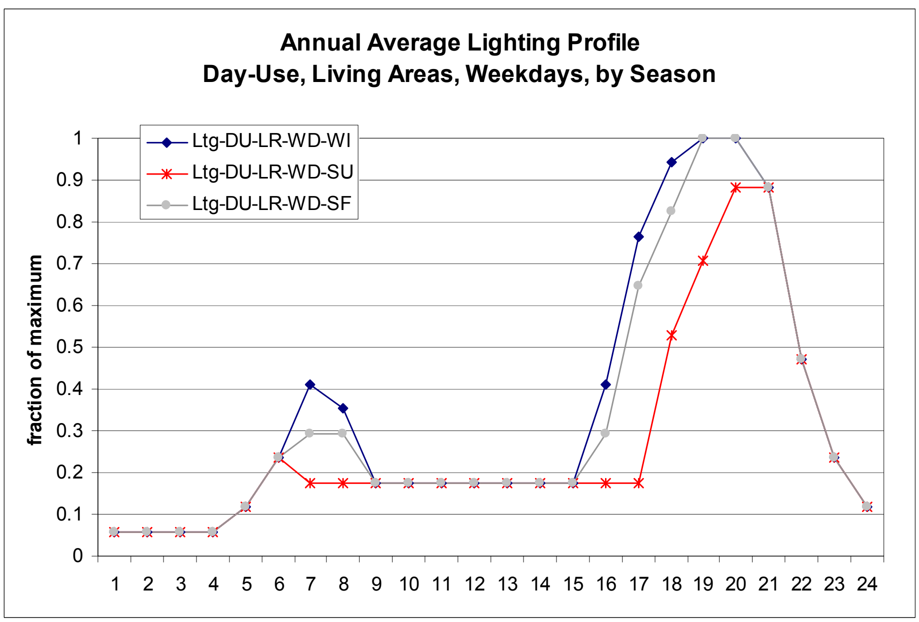

Figure 9. Example detailed lighting profile.

Room-to-room distribution of interior lighting energy and operating hours for the Benchmark shall be based on the summary in Table 8.

Table 8. Distribution of lighting energy by room type. (Based on Navigant, 2002)

	Room Type	Percent of Total Lighting Energy
Living Space	Kitchen	18%
	Dining Room	11%
	Family Room	7%
	Living Room	27%
Bedroom Space	Bathrooms	16%
	Halls	8%
	Master Bedroom	7%
	Other Bedrooms	6%

Appliances and Other Loads

As with lighting, several load characteristics must be defined for appliances and other plug loads: the amount of the load, the schedule of the load, the location of the load, the fraction of the load that becomes a sensible load, the fraction of the load the becomes a latent load. Though the load may be treated as an aggregate, each end-use must be considered separately. The breakdown of annual loads for major appliances and other equipment is shown in Table 9. The appliance loads were derived by NREL from EnergyGuide labels and from a Navigant analysis of typical models available on the market that meet current NAECA appliance standards. The daily loads rolled up at the whole-house level are shown in Table 10.

For a typical Building-America size house, the loads from occupants and most appliances are assumed to be a function of number of bedrooms. The exceptions are refrigerator and cooking loads, which are assumed constant regardless of number of bedrooms. The "Other Appliance & Plug Loads" end-use is assumed to be a function of finished floor area (Plug Load (kWh/yr) = 1.68 x FFA). This function reconciles total internal sensible loads (including people) for the Benchmark with the equation for internal loads in IECC 2003:

$$I_{Gain}\text{ (Btu/day)} = 17{,}900 + 23.8 \times CFA + 4104 \times N_{Br}$$

However, it should be noted that in the IECC equation, the total internal load is not a function of the number of bedrooms. It is therefore impossible to reconcile the Benchmark internal heat gain with IECC for all combinations of floor area and number of bedrooms. Instead, we chose to reconcile the internal loads for a typical 1800 ft^2, 3-bedroom house.

The constant internal load value of 72,000 Btu/day specified in NASEO 1999 is even less flexible than the equation in IECC 2003. However, the sensible heat load is approximately the same (73,052 Btu/day) for a typical 1800 ft^2, 3-bedroom detached house. In addition, Table 9 also reconciles latent load for a typically sized house with 20% of the sensible load, as assumed in NASEO 1999.

Table 9. Annual appliance and equipment loads for benchmark.[7]

Appliance	Electricity (kWh/yr)	Natural Gas (therms/yr)	Sensible Load Fraction	Latent Load Fraction
Refrigerator	669		1.00	0.00
Clothes Washer	$52.5 + 17.5 \times N_{br}$		0.80	0.00
Clothes Dryer (Electric)	$418 + 139 \times N_{br}$		0.15	0.05
Clothes Dryer (Gas)	$38 + 12.7 \times N_{br}$	$36 + 12.0 \times N_{br}$	1.00 (Electric) 0.10 (Gas)	0.00 (Electic) 0.05 (Gas)
Dishwasher	$103 + 34.3 \times N_{br}$		0.60	0.15
Range (Electric)	604		0.40	0.30
Range (Gas)		78	0.30	0.20
Other Appliance & Plug Loads	1.67 x FFA		0.90	0.10

[7] End-use loads in this table include only energy used within the appliance or equipment. Associated domestic hot water use is treated separately (see "Domestic Hot Water").

Table 10. Total rolled-up appliance and equipment loads for benchmark (1800 ft^2 prototype).

House Type	Electricity (kWh/yr)	Sensible Fraction	Latent Fraction	Nat. Gas (therms/yr)	Sensible Fraction	Latent Fraction
All Electric	5425	0.75	0.10			
Elec w/gas dryer	4666	0.85	0.11	72	0.10	0.05
Elec w/gas cooking	4821	0.79	0.08	78	0.30	0.20
Gas dryer/cooking	4062	0.92	0.08	150	0.20	0.13

The hourly load shape for interior residential equipment use is shown in Figure 10 (Huang 2002). The equipment profile is the sum of individual profiles of each piece of equipment, some of which are nearly constant (such as refrigerator and transformer loads) and some of which are highly dependent on time-of-day. NREL is in the process of developing hourly profiles for individual appliances. In the meantime, the equipment profile in Figure 6 may be used for either individual appliances or equipment in aggregate. Depending on the zoning of the building, all appliance loads should be modeled in the livings spaces (as opposed to bedroom spaces or outdoors).

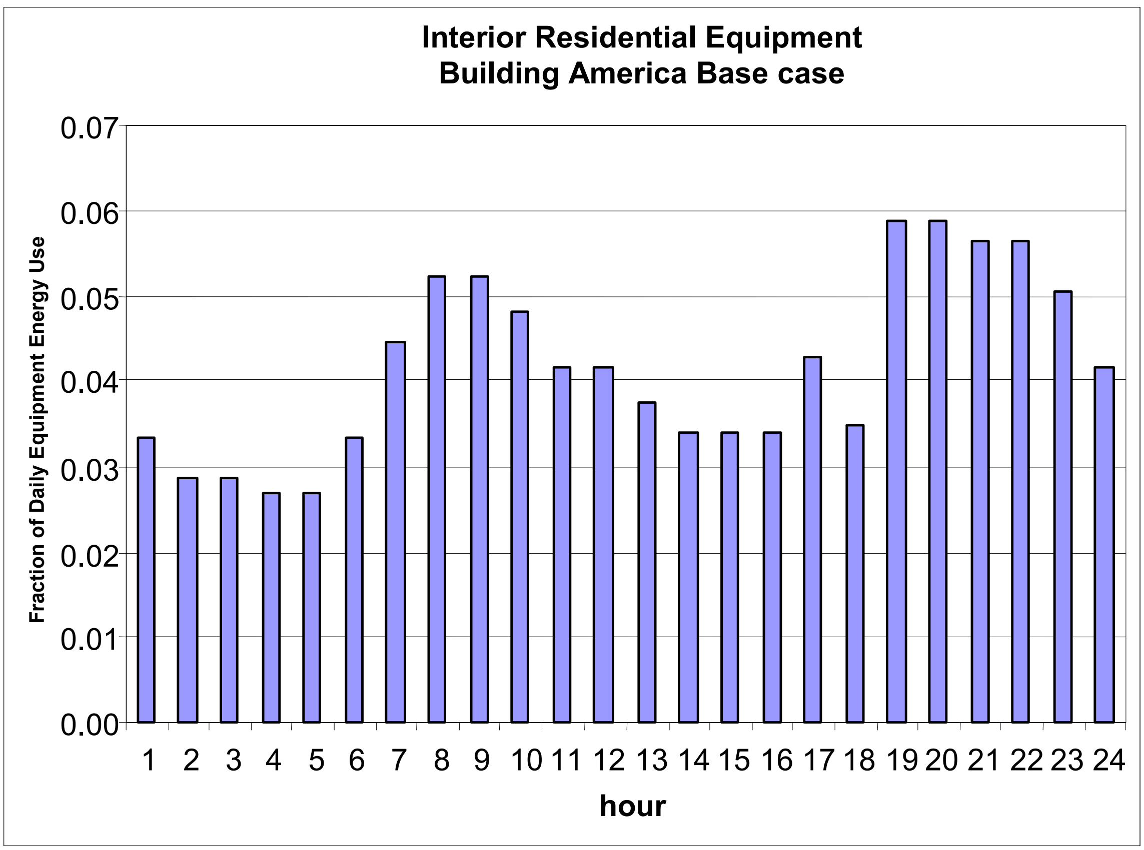

Figure 10. Interior Residential Equipment Profile

The installation of energy-saving appliances or other equipment in the Prototype building will change both the annual energy use and the hourly profile. Such measures may also reduce hot water consumption and space conditioning load. Energy savings calculations shall take these effects into account, using operating conditions based on rules developed for the Department of Energy residential appliance standards (DOE, 2003b). The number of cycles per year specified in the appliance standards for clothes washers, clothes dryers, and dishwashers shall be adjusted based on number of bedrooms using the following equation:

$$\text{Benchmark cycles per year} = (\text{Standard cycles per year}) \times (½ + N_{br}/6)$$

Large end-uses in the prototype that are not part of typical houses (such as swimming pools, jacuzzis, laboratories, etc.) shall not be included in the model for the benchmark or the prototype. The efficiency of these end-uses shall be addressed separately.

Occupant Loads

Occupancy schedule is defined with the same level of detail as other internal load profiles. For typical Building America houses the number of occupants shall be assumed equal to the number of bedrooms. Sensible and latent gains shall be accounted for separately, and different loads shall be applied in different space types, as summarized in Table 11 and Figures 11 and 12. The peak sensible and latent heat gains from occupants are based on ASHRAE recommendations (ASHRAE, 2001). Other values were developed by NREL based on engineering judgment.

Table 11. Sensible and latent heat gain from occupants (ASHRAE 2001).

Living Area Sensible Gain:	230	BTU/person/hr
Bedroom Area Sensible Gain:	210	BTU/person/hr
Living Area Latent Gain:	190	BTU/person/hr
Bedroom Area Latent Gain:	140	BTU/person/hr

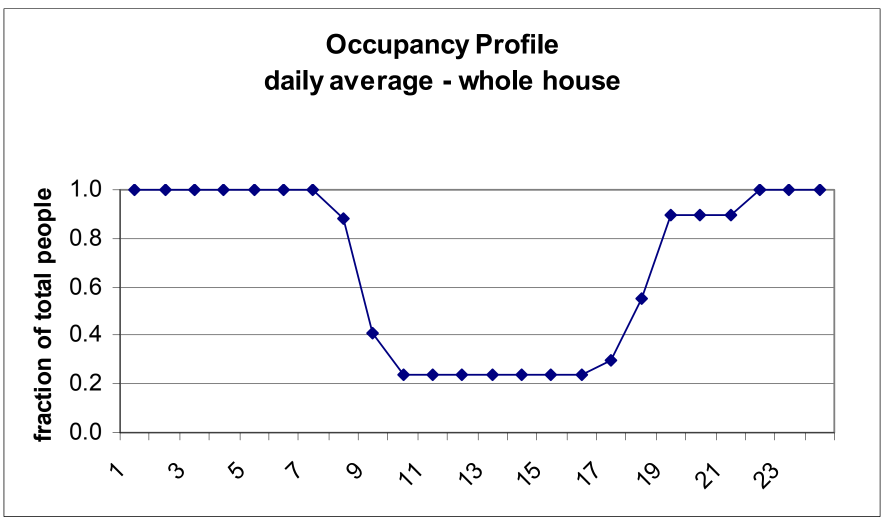

Figure 11. Average hourly load profile from occupants for all day-types and family types (16.5 hours/day total).

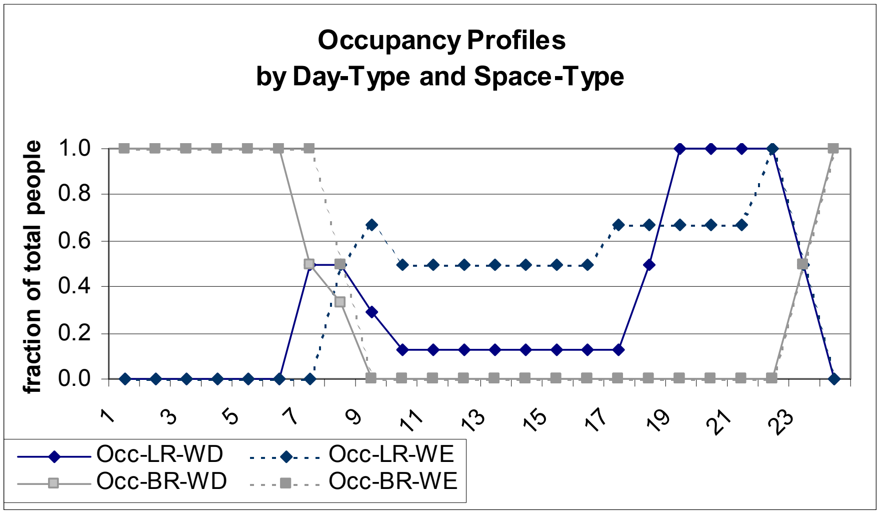

Figure 12. Detailed hourly load profile due to occupants for different day-types.

Operating Conditions

Operating conditions for both the Prototype and Benchmark shall be consistent with the NASEO HERS Guidelines (NASEO, 1999) with the following exceptions:

- Thermostat set point for cooling = 78°F, with no set-up period.
- Thermostat set point for heating = 68°F, with no set-back period.

The natural ventilation schedule shall be set to reflect windows being opened occasionally. In situations where there is a cooling load, the outdoor temperature is below the indoor temperature, and the window is not already open, the probability of the window being opened shall be set at a constant 50%. For tools that do not have the capability to calculate air infiltration effects caused by window openings, natural ventilation rates shall be set at 5 ACH unless each living area and bedroom provides at least two openings on different orientations and the net area of openings exceeds 12% of the floor area of the house (cross-ventilation), in which case a natural ventilation rate of 7 ACH shall be used. The availability of cross-ventilation shall be assumed for the Benchmark.

Internal mass of furniture and contents shall be equal to 8 lbs/ft^2 of conditioned floor space. For solar distribution purposes, lightweight furniture covering 40% of the floor area shall be assumed.

Heating and cooling shall only occur during certain months of the year in accordance with the following guidelines developed by FSEC, which serve as the basis for defining seasons in the EnergyGauge Software. Alternate operating profiles may be acceptable with sufficient justification.

The heating and cooling seasons shall be determined based on the Monthly Average Temperatures (MAT) and the Winter and Summer Design Temperatures (WDT and SDT, respectively) of the respective climate in accordance with the following procedures:

Step 1. MAT basis

(I) A month shall have the heating system enabled if the MAT is less than 71.5°F.

(II) A month shall have the cooling system enabled if the MAT is greater than 66°F.

Step 2. WDT and SDT

(I) December and January shall have the heating system enabled if the WDT is less than or equal to 59°F, regardless of the outcome in Step 1 above.

(II) July and August shall have the cooling system enabled regardless of the outcome in Step 1 above.

Step 3. Swing Season Adjustment

(I) If, based on Steps 1 and 2 above, there are two consecutive months where the heating system is enabled the first month and the cooling system is enabled the following month, or vice versa, then both the heating system and the cooling system shall be enabled for both these months.

Site Generation

The BA Benchmark shall not include site generation. All electricity is purchased from the local utility. In addition, no active solar water heating or space heating shall be included in the Benchmark.

For the Prototype, all site electricity generation is credited regardless of energy source. Residential scale photovoltaic systems, wind turbines, fuel cells, and micro-cogen systems are all potential sources for site electric generation. An offset must be applied to this electricity credit equal to the amount of purchased energy used in the on-site generation process. The credit for site generation shall be tracked separately from the whole-house energy analysis, and reported as a separate line in the summary tables (discussed in the next section).

Solar water heating is not categorized as "site generation" in the context of the Benchmark. It is treated as an energy efficiency measure under "Domestic Hot Water".

Reporting Energy Use and Energy Savings

Reporting energy use and energy savings in a consistent format is an important component of Building America analysis. The following tables shall be supplied with the analysis report for every Building America Prototype. The Benchmark version number shall be identified in the caption to ensure that the results are interpreted in the correct context, and not compared to results using a different version of the Benchmark.

Table 12 shows an example site energy consumption report for a hypothetical Prototype in Virginia, along with all relevant base cases. Similar information is presented based on source energy in Table 13, along with percent energy savings for each end use. The end uses are described in more detail in Table 14.

The "Percent of End-Use" columns in Table 13 show the Prototype energy use for each end-use as a fraction of the appropriate base case. The "Percent of Total" columns show the contribution of each end-use towards the overall energy reduction goal. Note that site generation for the Benchmark is always zero.

Source energy is determined as:

$$\text{Source MBTU} = \text{kWh} \bullet 3.412 \bullet M_e / 1000 \; + \; \text{therms} \bullet M_g / 10$$

Where: $M_e = 3.16$ = Site to source multiplier for electricity (DOE, 2002b).
$M_g = 1.02$ = Site to source multiplier for natural gas (DOE, 1995).

Table 12. Example summary of site energy consumption by end-use using Building America Research Benchmark Version 3.1.

	Annual Site Energy							
	BA Benchmark		Region Standard		Builder Standard		BA Prototype	
End-Use	kWh	therms	kWh	therms	kWh	therms	kWh	therms
Space Heating	11225	0	11286	0	11286	0	4397	0
Space Cooling	2732	0	2432	0	2432	0	902	0
DHW	4837	0	4838	0	4838	0	1351	0
Lighting	3110		3110		3110		1204	
Appliances + Plug	7646	0	7646	0	7646	0	7436	0
OA Ventilation	400		400		400		400	
Total Usage	29950	0	29712	0	29712	0	15690	0
Site Generation	0	0	0	0	0	0	7402	0
Net Energy Use	29950	0	29712	0	29712	0	8289	0

Table 13. Example summary of source energy consumption by end-use using Building America Research Benchmark Version 3.1.

	Estimated Annual Source Energy				Source Energy Savings					
					Percent of End-Use			Percent of Total		
End-Use	Benchmark MBTU/yr	Region MBTU/yr	Builder MBTU/yr	Proto MBTU/yr	BA Base	Reg Base	Bldr Base	BA Base	Reg Base	Bldr Base
Space Heating	115	116	116	45	61%	61%	61%	23%	23%	23%
Space Cooling	28	25	25	9	67%	63%	63%	6%	5%	5%
DHW	50	50	50	14	72%	72%	72%	12%	12%	12%
Lighting	32	32	32	12	61%	61%	61%	6%	6%	6%
Appliances + Plug	78	78	78	76	3%	3%	3%	1%	1%	1%
OA Ventilation	4	4	4	4	0%	0%	0%	0%	0%	0%
Total Usage	307	304	304	161	48%	47%	47%	48%	47%	47%
Site Generation	0	0	0	-76				25%	25%	25%
Net Energy Use	307	304	304	85	72%	72%	72%	72%	72%	72%

Table 14. End Use Categories

End-Use	Potential Electric Usage	Potential Gas Usage
Space Heating	Supply fan during space heating, HP, HP supplemental heat, Water boiler heating elements, Water boiler circulation pump, Electric resistance heating, HP crankcase heat, Heating system auxiliary	Gas furnace, Gas boiler, Gas back-up HP supplemental heat, Gas ignition stand-by
Space Cooling	Central split-system A/C, Packaged A/C (window or through-the-wall), Supply Fan energy during space cooling, A/C crankcase heat, Cooling system auxiliary	Gas absorption chiller (rare)
DHW	Electric hot water heater, HP water heater, Hot water circulation pumps	Gas hot water heater
Lighting	Indoor lighting, outdoor lighting	None
Equipment	Refrigerator, electric clothes dryer, gas clothes dryer (motor), cooking, miscellaneous	Cooking, gas clothes dryer
OA Ventilation	Ventilation fans, Supply air fan during ventilation mode	None
Site Generation	Photovoltaic electric generation	None

Table 15 reports energy savings for individual energy efficiency measures applied to the prototype, in terms of source energy and energy cost. "Source Energy Savings %" is determined by comparing the source energy for each measure increment to the source energy for the Benchmark (i.e. the first row). In this table, the incremental savings for each measure is added to the savings for all of the previous measures. The final row of this column is the overall energy savings achieved for this Prototype house. When available, actual energy tariffs for the prototype house shall be used to determine whole-building energy costs. Energy cost and measure savings are compared to Builder Standard Practice (representing a real design or set of practices that is currently being used by the builder) rather than to the Benchmark to provide an evaluation of the improvement in the performance of the Prototype compared to homes currently being sold by the builder partner.

Table 15. Example measure savings report[8] using Building America Research Benchmark Version 3.1.

					National Average		Builder Standard (Local Costs)			
	Site Energy		Est. Source Energy		Energy Cost		Energy Cost		Measure	Package
Increment	kWh	therms	MBTU	Savings %	$/yr	Savings %	$/yr	Savings %	value ($/yr)	savings $/yr
Bldg America Rsch Benchmark	29950	0	306.9		$ 2,995		$ 2,950			
Regional Std Practice	29712	0	304.4	1%	$ 2,971	1%	$ 2,927			
Builder Std Practice (BSP)	29712	0	304.4	1%	$ 2,971	1%	$ 2,927			
BSP + improved walls	27779	0	284.6	7%	$ 2,778	7%	$ 2,736	7%	$ 190.4	$ 190
BSP ++ Low-E Windows	25810	0	264.5	14%	$ 2,581	14%	$ 2,542	13%	$ 193.9	$ 384
BSP ++ Smaller A/C (5 -> 4 tons)	25420	0	260.5	15%	$ 2,542	15%	$ 2,504	14%	$ 38.4	$ 423
BSP ++ Inc. Bsmt Wall Insulation	25170	0	257.9	16%	$ 2,517	16%	$ 2,479	15%	$ 24.6	$ 447
BSP ++ Ground Source HP (+DHW)	19331	0	198.1	35%	$ 1,933	35%	$ 1,904	35%	$ 575.1	$ 1,023
BSP ++ Solar DHW	17718	0	181.5	41%	$ 1,772	41%	$ 1,745	40%	$ 158.9	$ 1,181
BSP ++ Lighting, Appl. & Plug	15690	0	160.8	48%	$ 1,569	48%	$ 1,545	47%	$ 199.8	$ 1,381
Site Generation										
BSP ++ PV	8288	0	84.9	72%	$ 829		$ 816	72%	$ 729.0	$ 2,110

[8] Calculated using national average electric cost = $0.10/kWh and national average gas cost = $.50/therm.

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